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Lubrication

A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Synthetic Oils for
Aircraft Gas
Turbine Lubrication

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LUBRICATION

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Synthetic Oils for Aircraft Gas Turbine Lubrication

DEVELOPMENT work in the field of synthetic lubricants may be traced back for at least three fourths of a century. In 1877 Friedel and Crafts produced a viscous hydrocarbon oil by treating amyl chloride with aluminum or aluminum chloride and hydrolyzing the resulting complex.

The first commercial production of synthetic hydrocarbon lubricating oils was carried out by Standard Oil Company of Indiana in 1929. These oils were wax free and possessed extremely low carbon forming tendencies. Their unusual properties made them well suited as lubricants in various types of equipment. Unfortunately limited demand and certain production difficulties caused their manufacture to be discontinued.

During the period from 1938 to 1945, Carbide and Carbon Company pioneered in the development of polyglycols. Some of these oils were extensively service tested in both military automotive and aircraft piston engines.

Much of the original basic research work on synthetic lubricants in the United States during 1942 to 1945 was carried out by Zisman and his co-workers of the Naval Research Laboratory. During this period, the diesters were recognized as offering the greatest promise for a variety of applications such as instruments, machine guns, cameras, optical equipment and aircraft gas turbines.

During the same period, German efforts were being concentrated on a more limited scale with the polyethylene type of synthetic oils to overcome cold weather problems in automotive, railway and miscellaneous applications.

Synthetic oils were adopted in place of mineral oils for most aircraft turbines about 1950 in Great Britain and only recently for several models of turbines in this country.

The discussion that follows offers a brief description of the aircraft turbine lubrication systems, the lubricant requirements, a review of the general properties of various synthetic lubricants and how certain ones meet these requirements. It is impossible in these few pages to cover the subject in detail. In effect, this discussion does little more than provide an introduction. The comments given are based upon the latest information available. It would be unwise to draw final conclusions from such information because of the changes from day to day. The comparisons shown of different classes of synthetic oils are based primarily on their possible use in the aircraft turbine.

DESCRIPTION OF LUBRICATION SYSTEMS

Compared with piston engines, the lubrication systems of turbojet and turboprop engines are quite simple. The essential components requiring lubri-

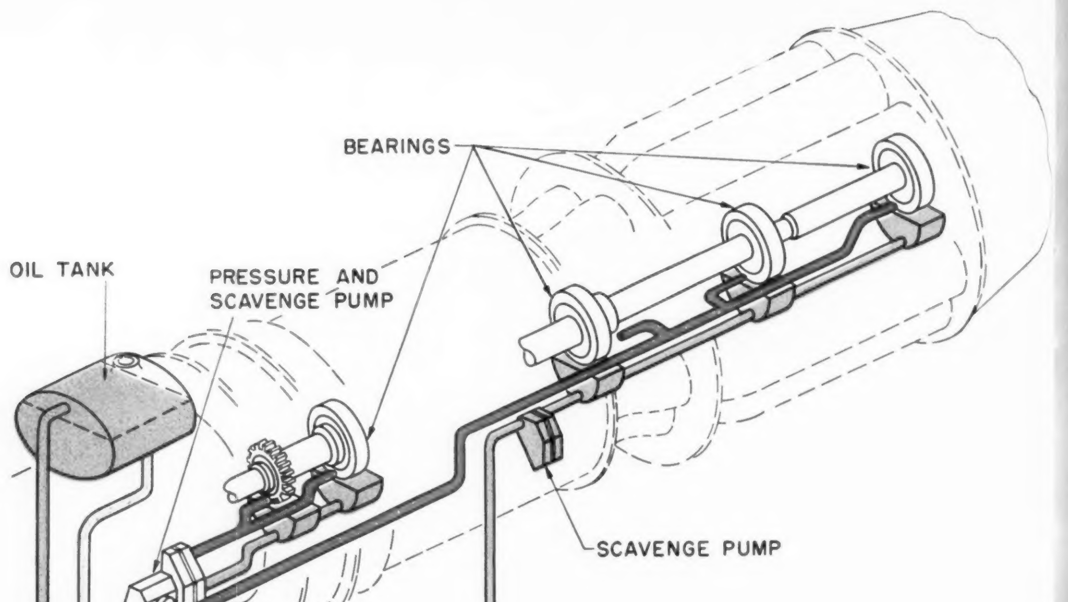


Figure 1 — Lubrication system of a typical turbojet engine.

cation in the turbojet engine are main shaft bearings and accessory drive gears. In some engines, the lubricant also serves as a hydraulic fluid for actuating fuel controls.

Ball and roller bearings have replaced plain bearings in virtually all cases for main shaft and accessory drive shafts. The advantages realized with former class of bearings in these locations are: lower starting torque, ability to operate for short periods without a continuous oil supply, reliable operation with low viscosity oils and more suitable for high temperatures.

In turboprop engines, the reduction gear must be included among the important components requiring lubrication. In current engines, these gears are supported by sleeve type or ball bearings.

Oil for actuating propellers may be supplied from the main engine supply or from a separate system carried within the propeller hub. The propeller requirements therefore may play a part in the selection of type of oil for the turbine.

The dry sump system generally is used for gas turbine power plants; similar in many respects to the large piston engine. Oil usually is carried in an external tank. Some turbines, however, utilize the lower portion of the accessory case for the oil reservoir. The tank may be mounted on the outside of the turbine or elsewhere in the engine nacelle or wing.

Oil enters the pressure pump from the tank or reservoir. From the pump oil usually passes through a fine mesh strainer or filter and then branches out to each bearing and coupling on the main shaft as well as to various jets in the accessory section. An orifice usually is placed in each supply line to meter or proportion the flow to each component or assembly. In a majority of turbines the supply of oil to the main bearings is in the form of steady jet from small nozzles. This oil then is scavenged from each bearing housing and returned to a heat exchanger and tank.

In some engines, the oil supply to the main bearings is metered either directly into the bearing or into a cooling air stream where it is atomized. With the metered supply the excess is allowed to drain overboard.

Lubrication of the reduction gear assembly in turboprop engines follows piston engine practice

rather closely. (See Magazine LUBRICATION May 1951 "Aircraft Engine Oil Systems".)

Compared with piston engines, the heat rejection to lubricating oil in turbojet engines as a function of fuel flow is relatively small. Consequently, it is possible to transfer this heat to the fuel supplied to the engine. This method of utilizing fuel for oil cooling is now proving quite successful in modern high speed aircraft.

Heat rejection to oil in turboprop engines is much greater than with turbojet due to the reduction gear. Slower speeds of such aircraft and higher heat rejection rates favor the conventional oil cooler similar to those used with piston engines.

General Lubrication Requirements

Of the numerous requirements for an aircraft turbine lubricant, perhaps the following represent the three most important:

1. Low temperature fluidity
2. High temperature stability
3. Gear lubrication

Other requirements that also must be taken into consideration are compatibility with metals, volatility, hydrolytic stability, toxicity, availability and cost.

Low Temperature Requirement

A turbine lubricant must permit starting on the ground or in flight at the lowest anticipated temperature. While preheating and dilution of lubricating oils are accepted for piston engines, they are not favored for the military aircraft turbine at the present time. Dilution of lubricating oil is more or less impractical due to lower volatility of fuel and insufficient heat in most turbines to boil off the diluent. Another possible objection to dilution might be found in the loss of diluent in certain regions due to high temperatures following shutdown. Since most turbines can be designed to operate successfully on low viscosity oils, there is probably little reason to call upon these starting aids. The first requirement then is for the lubricant to be capable of pumping at the lowest starting temperature.

There are two different viewpoints on this requirement. First, the U. S. Military Services specify −65°F. and second, the British −40°F. as the minimum starting temperatures. In many cases these requirements are not interchangeable. Lubricants developed to meet the −65°F. requirement cannot be used successfully in most turbines designed to meet the −40°F. starting temperature. It also is quite apparent that the reverse invariably holds true, where an oil just meets the pumpability requirements of −40°F., it cannot meet the −65°F. requirement. Two entirely different synthetic lubricants are required, one for U. S. Military (−65°F.)

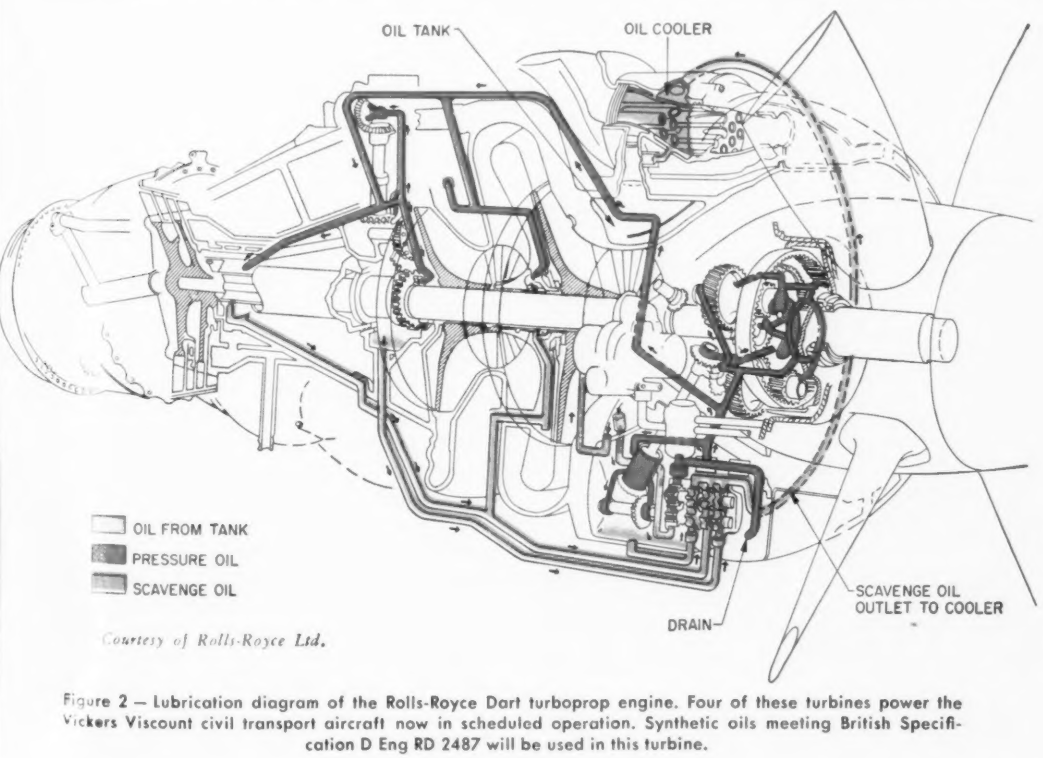


Figure 2 — Lubrication diagram of the Rolls-Royce Dart turboprop engine. Four of these turbines power the Vickers Viscount civil transport aircraft now in scheduled operation. Synthetic oils meeting British Specification D Eng RD 2487 will be used in this turbine.

Figure 3 — Photo of Convair XF-92A delta wing aircraft. This experimental ship is the forerunner of supersonic delta wing fighter type of aircraft.

and a second for the British (−40°F.).

Operation of military aircraft over the North American Continent during the past 12 or 13 years has stressed the need for meeting the −65°F. starting temperature requirement for this particular area. Restarting of turbines in flight with multi-engine aircraft may impose even lower starting temperature requirements than the −65°F. ground starting condition.

In the case of civil or commercial operations, this requirement may be somewhat milder. Present experience seems to indicate that a minimum starting temperature of −40°F. will suffice for all except a few rare cases.

Low temperature pumpability tests in the United States and Great Britain show unusually good agreement with regard to the maximum permissible viscosity. This value varies from one installation to another according to design of engine, oil tank location, plumbing, etc.

Low temperature pumpability tests conducted recently by the Aeronautical Engine Laboratory* of the U. S. Navy Bureau of Aeronautics with a simulated oil system revealed the following.

With a constant displacement pump, aerated and deareated oils, pressure altitudes from sea level to 70,000 feet and temperatures from 40°F. to −70°F.:

(a) Pumpability is a function of viscosity, absolute pump inlet pressure, and amount of aeration of the oil.

(b) The configuration of lines on the discharge side of the pump has little or no effect upon the pumpability characteristics of the oil.

(c) The critical viscosity for deaerated oil at sea level for full flow was approximately 6000 cs. For aerated oil the critical viscosity was approximately 3900 cs. At higher viscosities pump cavitation occurred and delivery rates decreased with increase in viscosity. The maximum permissible viscosity for satisfactory starting was estimated to be roughly 10,000 cs.

Some of the early full scale J-47 low temperature starting tests conducted by General Electric Company* with mineral oils also revealed some interesting data. The critical viscosity where pump cavitation began to show up was approximately

*"Flow Characteristics of Turboprop Lubricants". Aeronautical Engine Laboratory, Naval Air Experiment Station, Naval Air Material Center — Philadelphia, December 5, 1952.

*"Eglin Field TG-190 Extreme Weather Test", G. E. Report November 10, 1948, No. DF81730.

Courtesy of Wright Aeronautical

Figure 4 — Aircraft turbine bearing from high temperature accelerated test with MIL-L-7808 type of synthetic oil at 700°F.

2500 cs. At 7500 cs. viscosity pump cavitation was so complete that the oil would not warm up after a reasonable idling period to permit the engine to be run at higher speeds. For reliable engine operation without any restrictions as to speed or length of warm-up, General Electric therefore recommended a maximum viscosity at −65°F. of 3000 cs. for the J-47 engine.

High Temperature Requirements

The components in a turbine that operate at the highest temperature are the bearings on the main shaft. In addition to these bearings some parts of the engine frame and bearing support housings may also expose lubricating oil to high temperatures.

The maximum operating bearing temperatures in the majority of turbines already in service fall in the range of 250-300°F. With bearings next to the turbine wheel a soak-back effect occurs following shutdown. Heat accumulated in the turbine wheel disk flows into the cooler turbine bearings when the oil flow is stopped at time of shutdown. This causes a brief rise of roughly 150°F. and followed by a slow cooling off of the entire engine. The peak temperatures during this brief period frequently reach values between 400-450°F. With low viscosity mineral oils evaporation of oil during this period is quite rapid. Hence, oil volatility is important. These conditions, however, from a high temperature point of view, are what might be called mild and present no serious problems. In this class of turbine the low viscosity mineral oils have served very well.

In some recent turbines with higher pressure ratios the high temperature requirements are much more severe. Normal bearing temperatures during operation are now reaching as high as 475°F., fully 200°F. higher than in previous turbines. The soak-back effect may add another 100-150°F. for brief periods following shutdown. Thrust bearings opposite the compressor discharge location also may exceed temperatures of 400°F. In addition, parts of the engine frame in this region may run close to 600°F. Unfortunately, the highest gas pressures in the entire cycle are at this location, making it difficult to circulate low pressure cooling air in this region. The simplest approach then is to throw most of the burden of cooling on the lubricating oil. These are some of the reasons for introducing the panel coking test in present MIL-L-7808 synthetic oil specification. Except for the thrust bearing and for gyroscopic loads, loads carried by the main shaft bearings are very light. Fortunately, these gyroscopic loads do not impose a serious problem because of their extremely short duration.

Rotor speeds will vary from 20,000 rpm for smaller turbines to below 7000 rpm for larger units. DN values (diameter of bore in mm., N = rpm) now are running close to 1,000,000. Future DN values are expected to reach 1,500,000.

A turbine lubricant, therefore, must be thermally stable in bearings operating at 500°F. and shall not form objectionable deposits when in contact with hot surfaces of 600°F. for short periods. Also, it is necessary for a turbine oil to be non-corrosive to the various metals present in bearings and other sections at high temperatures.

Courtesy of Wright Aeronautical

Figure 5 — Deposits found in oil line of high temperature bearing test machine after operation on silicate ester blend.

Gear Lubrication

The ability to lubricate highly loaded gears is the third important requirement of an aircraft turbine lubricant. Undoubtedly, this requirement is of greater importance in the case of the turboprop engine than with the turbojet. In the former the weight of the reduction gear represents roughly 20% of the power plant weight. Therefore, the ability to operate at high gear loads means lighter gears and an appreciable saving in weight.

According to Ryder* a design Hertz stress of 125,000 to 140,000 psi is permissible for aircraft engine gears. In the Ryder gear test machine, a Hertz stress of 125,000 psi is obtained at an indicated load of 1050 lb. per inch width (PPI) of tooth (See Page 55 for a description of the Ryder Gear Test Machine). 140,000 psi Hertz corresponds to 1340 PPI. It is obvious that scuffing values should be greater than 1050 to 1340 for successful performance of a turbine gear box.

Oils having scuff values of 200-700 PPI in the Ryder gear test rig allow immediate scuffing and scoring. Oils falling in the range of 1000-1400 PPI are found to be borderline. Oils having scuff values of 1700-2250 PPI and upward have been quite satisfactory in the full scale engine.

In the final analysis, most designers want a synthetic turbine lubricant that will match the load carrying property of Grade 1100 Mineral Oil (Specification MIL-O-6082).

*"The Development of Significant Bench Tests for Aircraft Turbine Lubricants". E. A. Ryder, Lubrication Engineering, August 1953.

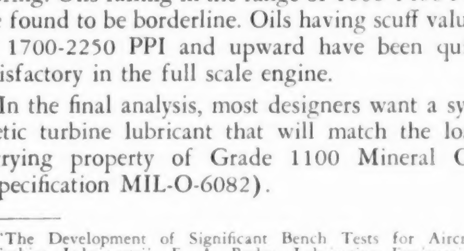


Figure 6

Other Requirements

Compatibility with various metals used in turbine design is important. In addition to the high temperature and corrosion resistant ferrous alloys modern practice includes copper and its alloys, silver, aluminum, magnesium and lead. Titanium and its alloys also are beginning to make their appearance. Use of cadmium and zinc is questioned at present because they frequently react with oxidation products and additives. The latter two metals are used largely for plating and corrosion protection of miscellaneous parts.

Volatility also is an important factor in the selection of a turbine lubricant. The objections found with highly volatile oils are serious lacquering, high oil consumption and loss of lubricant following shutdown of the turbine. This is one of the properties favoring the selection of synthetic oils over mineral oils.

Since all oil systems in aircraft collect small amounts of water from time to time, hydrolytic stability is an essential requirement. In addition to resistance to hydrolysis a lubricant should not form a gel or solid material in the presence of water.

In some designs of turboprop engine a lubricating oil also serves as the hydraulic oil for propeller governing. The British experience thus far has found that kinematic viscosities below 7.5 cs @ 210°F. resulted in excessive leakage in the governor mechanism and poorer control over engine speed. This is not necessarily a hard and fast requirement and may change with new designs. It is not a factor where the propeller carries an independent supply of hydraulic oil.

Bleeding air from the turbine compressor for cabin pressurization has introduced the question of toxicity. With this system of cabin pressurization any oil leakage into the compressor will, of course, result in vapors or oil mist entering the cabin. This problem is one of the most controversial at the moment. However, in the final analysis it may be stated the synthetic oil should not be more toxic than mineral oil.

REVIEW OF DIFFERENT CLASSES OF SYNTHETIC OILS

Chlorinated Hydrocarbons

Chlorinated hydrocarbons are considered from time to time as lubricants. Their principal advantages appear to be good wear prevention or high E.P. properties and reduced flammability. Their principal uses appear to be confined to heat transfer fluids and certain non-flammable hydraulic fluids. For gas turbine lubrication, the most serious objections (Table I) are poor viscosity — temperature

TABLE I

COMPARISON OF VARIOUS SYNTHETIC OILS WITH MINERAL OIL

Kinds that meet viscosity characteristics required for aircraft gas turbines.

Requirement	Chlorinated Hydrocarbons	Silicones	Organo Phosphorus Compounds	Silicate Esters	Poly-glycols	Diesters
Viscosity-Temperature Characteristics	Poor	Outstanding	Fair to good	Excellent	Good to Excellent	Excellent
Volatility	High	Very low	Lower	Very low	Low	Very low
Thermal oxidation stability 400-600°F.	Fair to good	Poor to fair	Poor	Fair to poor	Fair	Good
Wear Prevention	Good	Poor	Excellent	Fair	Good	Good
Corrosion to Metals	Poor	Good	Fair	Good	Good	Good
Hydrolytic Stability	Fair to good	Good	Fair to good	Fair to poor	Good	Fair to good
Flammability	Less	Less	Less	Same	Same	Same
Rubber Swell	Very high	Low	Very high	Low	Same	High
Cost	High	Extremely High	Very high	Very high	High	Very high

characteristics, toxicity and very high rubber swelling. On the basis of present knowledge, this class of oil holds little promise as a turbine lubricant.

Discussions on chlorinated hydrocarbons often raise questions regarding the possible use of fluorinated hydrocarbons. While the latter exhibit remarkable oxidation resistance and high thermal stability, they unfortunately have three serious objections for use as turbine lubricants: first, poor viscosity-temperature characteristics; second, the range of temperature between freezing and boiling points is too narrow when compared with analogous hydrocarbons; and third, many exhibit bad rubber swelling characteristics.

Silicones

The outstanding property of silicones, as is well known, is the remarkably flat viscosity-temperature curve (Table I). Of all the pure compounds known today, silicones are by far the outstanding ones in this respect. For example, one of these fluids has a kinematic viscosity at 100°F. of 39.75 centistokes (roughly four times greater than Grade 1010 mineral oil) and at −65°F. 668 centistokes or about 3% of the Grade 1010 viscosity at this temperature.

Although silicones have unusually good oxidation resistance at moderate temperatures, it has been pointed out by Zisman* and his co-workers that they have the unfortunate property of forming gels once they do oxidize. While the methyl phenyl substitution on the polysiloxane chain is noticeably better than the dimethyl polymer, it falls short of permitting its use in the aircraft turbine with safety. No practicable anti-oxidants have been found to improve on this property.

Boundary lubrication properties of silicones have been studied by the Naval Research Laboratory with over 156 metal combinations. With the exception of steel on steel, and a few other hard metals, all other metal combinations appeared to work about as well as mineral oil. With steel on steel the resulting welding and tearing was so serious as to limit the application of silicones to very low unit loads.

A third disadvantage is their poor adsorption by steel at ordinary temperatures and therefore poor protection to rusting. Of the three drawbacks perhaps the most serious one insofar as turbine lubrication is concerned, is the gel formation at high temperatures.

Organo Phosphorus Compounds

The principal advantages of organo phosphorus compounds for various aircraft uses are excellent wear prevention (or lubricity) and lower flammability (Table I). Other advantages of some are fair to good viscosity-temperature characteristics and lower volatility compared with mineral oils. For temperatures below 300°F. this class of compound remains fairly stable and is compatible with most metals. However, its chief drawback as a potential

*"Present Problems and Future Trends in Lubrication". W. A. Zisman Naval Research Laboratory Report, November 26, 1952. "Dimethyl-Silicone-Polymer Fluids and Their Performance Characteristics in Hydraulic Systems". V. G. Fitzsimmons, D. L. Pickett, R. O. Militz and W. A. Zisman, ASME May 1946, Page 361.

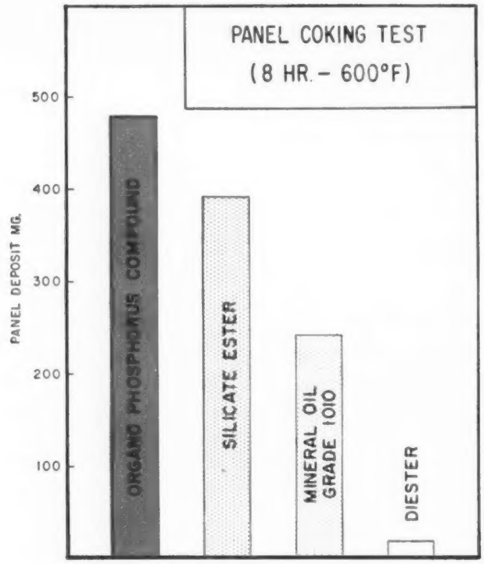


Figure 7

turbine lubricant is its poor thermal stability at high temperatures. The panel coking value (8 hrs. at 600°F.) of a typical organo phosphorus compound is around 480 mg. (See Fig. 7.)

Hydrolytic stability of this class of compound varies from fair to good. This property is not as bad as is found with silicate esters but is not as good as the diesters. Those compounds which are susceptible to hydrolysis may form objectionable amounts of corrosive phosphoric acids.

High rubber swell has presented some problems. However, progress has been made by changing formulation of the elastomers involved.

The principal uses of this class of synthetic oil for aircraft at present are for hydraulic systems of commercial aircraft, cabin supercharger drives and lubricating oil additives. In some respects, this class of fluid offers improvements over mineral oils for moderate temperatures up to 300°F. but should not be applied to turbines because of poor thermal stability at higher temperatures.

Silicate Esters

Silicate esters recently have attracted a considerable amount of interest as high temperature hydraulic fluids and turbine lubricants. From the simple physical tests, they may appear at first glance to be very attractive. For example, the viscosity temperature characteristics and volatility are outstanding (Table I). Their performance as gear lubricants appears satisfactory. These oils are non-corrosive to most metals and also possess relatively low rubber swell tendencies.

Two very serious objections have been found thus far with silicates; first, poor thermal stability and second, unsatisfactory hydrolytic stability. Both of these disadvantages appear to be inherent with the structure of these fluids. Up to the present time there does not seem to be a way to overcome them. For example, the Panel Coking Test value is very high (390 mg.) see Fig. 7. Furthermore, the nature of the deposits are gritty and very abrasive. This limitation is such that the lubricant never should be exposed to temperatures in excess of 400°F.

Perhaps the most serious objection to silicate esters as potential turbine lubricants is their poor hydrolytic stability. What it means is simply this: Any water that comes in intimate contact with many of these silicates will cause them to break-down forming a gel and large quantities of abrasive silica (see Figs. 8 and 9). On the basis of the latest knowledge concerning silicates, they do not appear promising for these purposes.

Polyalkylene Glycols and Derivatives

The polyalkalene glycols or polyethers and their derivatives are a very interesting family of compounds with an extremely broad field of application. As reported by J. M. Russ* the uses of these lubricants include internal combustion engines, gears, compressors, vacuum pumps, heat transfer fluids, fire resistant water base hydraulic fluids and many others. Both water soluble and water insoluble compounds are available in a wide range of viscosities.

The most promising of the glycols as potential

*"'Ucon' Synthetic Lubricants and Hydraulic Fluids" by J. M. Russ, Jr., ASTM Symposium on Synthetic Lubricants, June 194?, Publication No. 77.

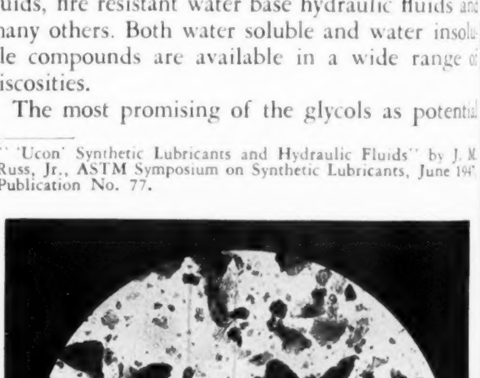


Figure 8 — Photomicrograph of silica formed from hydrolytic stability test of silicate ester fluid.

Organo phosphorous compound—satisfactory.

Silicate ester—fail. Note gel that formed and adhered to sides of bottle.

Grade 1010 mineral oil—pass.

Diester oil—pass.

Figure 9 — Hydrolytic stability test with various oils.

turbine lubricants are the doubly chain-stoppered variety. These have excellent viscosity temperature characteristics and much lower volatility than mineral oil (Table I). An example of one of these experimental fluids appears on Table II.

Other characteristics that make the glycols attractive as aircraft turbine lubricants are good thermal stability, good wear prevention, non-corrosive to metals, low cost and good potential availability.

In the absence of oxygen, thermal stability of glycols is quite good as illustrated by their use as heat transfer fluids where temperatures of 450 to 500°F. exist for extended periods. Their oxidation stability, however, is not too good although this objection can be largely overcome through the use of certain anti-oxidants. These oils exhibit a certain amount of solvent action for their oxidation products. The latter may be either soluble in the liquid or volatile. If the lubrication system is vented to the atmosphere to permit the volatile oxidation products to escape, the high temperature components as well as the oil may remain remarkably free of sludge and deposits. The potentialities of glycols as turbine lubricants has not been fully realized especially where the more moderate low temperature starting requirements may be found. The greatest field for these lubricants at present appears to be for those turbines required to meet —40°F. starting temperatures such as the present requirements of British turbines, as well as future civilian or commercial turbine types of power plants. Mixtures of glycols and diesters at the present time also appear promising.

Esters

Monoesters as a class generally are not attractive for aircraft turbine lubrication because freezing points are relatively high and slopes of viscosity temperature curves for some are not very attractive. There are a few exceptions on which further study appears justified, such as monoesters of pelargonic acids.

The aliphatic diesters, made from dibasic acids, appear at present to be the most promising of not only all esters but of all synthetic lubricants. These diesters are outstanding with respect to excellent viscosity-temperature characteristics, high thermal stability, low volatility and wear prevention (Table I). They also are generally non-corrosive to metals, stable to hydrolysis, relatively non-toxic and similar to or slightly less flammable than mineral oils.

Two disadvantages are present; first, higher cost and second, higher rubber swell. These disadvantages, however, have not proved to be serious with respect to their use in the aircraft turbine. The raw materials used in the manufacture of diesters come from many different sources such as petroleum, animal fats, vegetable oils, sugar, turpentine, etc.

Triesters, tetraesters and other polyesters show considerable promise as high viscosity blending agents. Most of these are too high in viscosity and freezing points to be used as unblended oils in the

aircraft turbine. Some of these polyesters also exhibit remarkable thermal stability.

Most Promising Synthetic Oils

Of the thousands of synthetic oils examined for possible use in the aircraft turbine, two types appear the most promising.

a. Aliphatic diester

b. Polyglycol (doubly chain-stoppered)

The pertinent characteristics of finished oils falling in these two classifications as compared with a mineral oil are shown in Table II. In selecting oils for this comparison the viscosity at −65°F. was narrowed down to the range of 8000-10,000 cs. For the mineral oil a blend of grades 1005 and 1010 (MIL-O-6181A) was prepared with a −65°F. viscosity of 8380 cs.

Of the three oils shown the diester appears to be the first choice with respect to viscosity-temperature characteristics, evaporation (volatility), Panel Coking (High Temperature Stability), and Ryder Gear Scuff values.

While the full possibilites of the polyglycol oils have not been fully realized, they seem to rate second to the diester. Where low temperature starting requirements are not as severe, the polyglycols are more attractive especially if cost is a factor in the selection.

High Temperature Bearing Test

With the possible exception of a full scale engine test one of the most valuable lubricant tests is the high temperature bearing test. Such a "bench test" can establish high temperature stability, volatility, ability to lubricate a bearing, tendency to form deposits and compatibility with certain metals.

These high temperature bearing tests were devised originally to investigate metallurgy, bearing design, design of housings and seals. However since many of these bearing test rigs have correlated so well with the full scale turbine, they are proving equally useful for investigation of lubrication problems.

One of the outstanding bearing test machines used for testing synthetic oils is the Napier rig. This test method now is a requirement in the British Ministry of Supply Specification No. DEngRD 2487, Synthetic Type of Aircraft Turbine Engine Lubricating Oil. This rig employs 2 inch I.D. ball bearings operating at 21,000 rpm and 280°C (536°F.), test cycle covers ¾ hr. from ambient to 280°C. and 6½ hrs. at 280°C. Oil flow through each bearing 3 pt./hr.

Note: Above test cycle is repeated until significant deposit is formed to interfere with bearing operation, or until bearing shows signs of failure.

DN values (Bore dia. mm. x rpm) of the Napier Bearing Test are over 1,000,000 representing conditions typical of recent turbine design practice.

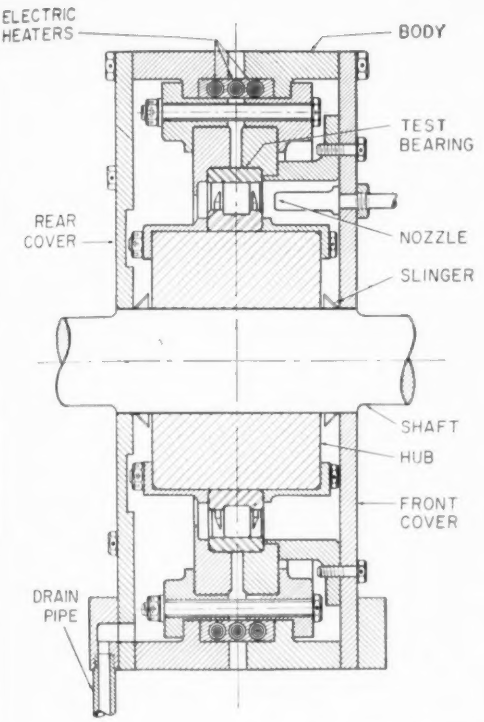
Wright Aeronautical (U. S.) also has found their high temperature bearing test rig (Fig. 10) to be very worthwhile for investigation of bearing and lubrication problems. This machine also operates at DN values in excess of 1,000,000. Unlike the Napier rig that uses a solid oil jet and recirculation the Wright Aeronautical rig has a metered oil flow corresponding to the type of oil system in one of the bearings of a current model of turbine. Test conditions are: bearing size 127 mm bore, speed 8300 rpm, outer race temperature 700°F., oil flow ½ lb./hr. (single bearing) and 7 hrs maximum duration.

TABLE II

COMPARISON BETWEEN MINERAL OIL AND EXPERIMENTAL POLYGLYCOL AND DIESTER OILS WITH VISCOSITIES @ −65°F. BETWEEN 8,000 AND 10,000 CS.

	Mineral Oil Blend Grades 1005 + 1010	Polyglycol Oil (With additives)	Diester Oil (With additives)
Viscosity cs.,			
@ −65°F.	8380	10,300	8710
100	7.42	10.65	12.77
210	2.05	3.19	3.35
Flash Point, °F.	260	360	425
Evaporation, %			
22 hrs. at 275°F.	56.2	——	0.73
6½ hrs. at 400°F.	97.0	31	8.0
Panel Coking, 8 hrs. at 600°F., mg.	387	N. A.	63
Ryder Gear Scuff, PPI			
(Average of two tests)	650	N. A.	2130

N. A. — Not available.



Courtesy of Wright Aeronautical

Figure 10 – Wright Aeronautical High Temperature Jet Engine Bearing Tester.

Panel Coking Test

One of the significant oil tests carried over from the piston engine to the turbine field is the Panel Coking Test. (Fig. 11.) This method was devised originally by the California Research Corporation. In its original form it was used to determine tendencies of piston engine oils to produce rocker box coking. Pratt & Whitney Aircraft subsequently made some modifications in the method and found it well suited to determine high temperature stability of turbine lubricants. It is now an established test method in the U. S. Military Specification MIL-L-7808.

This method employs an inclined aluminum test panel held at 600°F. The test oil is carried in a bath below the test panel and a motor driven rotary brush splashes oil against the underside of the panel.

The temperature of the test panel is held at 600°F. for a period of 8 hours. The present limit allowed is 100 mg. A comparison between the values obtained with various synthetic and mineral oils appears in Figure 7.

This is strictly a quantitative test and measures only the amount of deposit adhering to the panel. It does not indicate whether the deposit is comparatively harmless to bearings or whether of a gritty abrasive nature.

Ryder Gear and Lubricant Test

Two methods are currently used for testing the

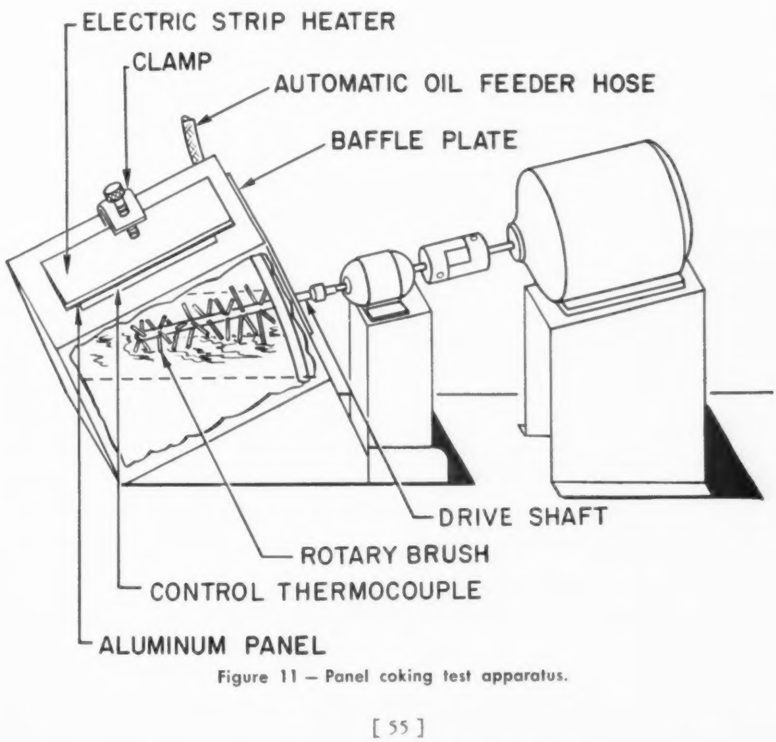


Figure 11 – Panel coking test apparatus.

TABLE III

Comparison of Ryder Gear Test Values for Mineral and Synthetic Types of Aircraft Engine Oils

	Oil Viscosity CS. @ 100°F.	Ryder Scuff Test	
		No. Tests	Average Value P.P.I.
Mineral Oils			
Blend-Grades 1005 and 1010	7.42	2	650
Grade 1065	114.7	4	1240
Grade 1100	249.3	6	1950
Synthetic Oils			
Diester Base Oil	14.2	2	1030
MIL-L-7808 Type (with additives)	12.77	2	2130
D Eng RD 2487 Type (with additives)	38.0	2	2490

ability of synthetic oils to lubricate gears; first is the I.A.E. Machine used in Great Britain and second, the Ryder Gear and Lubricant Tester employed in the U. S. Both test machines are somewhat similar in general arrangement although the latter operates at much higher speeds.

Of the countless number of so-called E.P. bench tests, none thus far have shown any satisfactory correlation with full scale engines. Their acceptance, therefore, in the field of synthetic lubricants is extremely limited. Certainly the results obtained from such E.P. test machines cannot be applied directly to design of the aircraft gas turbine.

The original Ryder Machine was built in 1941 for the purpose of testing gear materials and lubricants for the piston engine. Unlike so many E.P. bench tests, the Ryder Machine used actual gears from typical engines as test specimens. After making some improvements, Pratt & Whitney Aircraft found it to be quite useful for piston engine reduction gear problems.

The present Ryder Machine used for testing synthetic lubricants consists of a hydraulically loaded "Four Square" rig. The test gears are mounted on two parallel shafts, one driven by the other through helical gears. The axial load on each shaft is created by hydraulic pressure on each piston and helical gear. Loads on the test gears then is directly related to hydraulic pressure.

The present method calls for operation at 10,000 rpm or a pitch line speed of 9160 feet per minute. Each test employs a new set of gears (or new face).

The test procedure consists of a series of ten minute runs with an inspection of gear teeth after each run until 22½% of the tooth area has been scuffed.

A comparison of Ryder Gear Test values for various aircraft engine and turbine lubricants is shown on Table III.

Although the Ryder machine is one of the best of the available methods more experience is needed to determine its reproducibility, correlation and significance to full scale engine results.

SUMMARY

An aircraft turbine lubricant must fulfill three important requirements: first, be low enough in viscosity at the starting temperature to permit oil to flow to the pump; second, remain stable at higher temperature; and third, lubricate highly loaded gears.

At present, U. S. Military operations require that aircraft turbines start at −65°F. while British specify −40°F. At each of these temperatures it has been found that a kinematic viscosity somewheres between 3000 and 10,000 centistokes is required.

Maximum operating bearing temperature is approaching 500°F. in a number of recent aircraft turbines. The temperature rise following shutdown or "soak-back" may add another 100 to 150°F. to the operating temperature. A lubricant, therefore, must withstand these conditions without excessive evaporation or the formation of harmful deposits.

A synthetic lubricant in addition to meeting the requirements of both extreme low and high temperatures must carry about the same gear loads as the high viscosity aircraft engine oil, Grade 1100.

In a majority of turbojet engines already in service, mineral oils have given good results over the temperature range from −65°F. to +300°F. For some of the newest models of turbojets synthetic oils are required for the temperature range of −65°F. to +500°F. To what extent the bearing temperatures will be permitted to rise in future engines cannot be predicted at present.

Although the gear test rigs show that synthetic oils are equivalent to Grade 1100 mineral oils much more experience in full scale turboprop engines is required to confirm this point.

Undoubtedly in the next few years other new and interesting synthetic oils will be prepared and certainly the knowledge covering the performance of present oils in turbines will grow rapidly.

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